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Effects of Tactile Alerts on Concurrent Performance of the Gunner's and Robotic Operator's Tasks in a Simulated Mounted Environment

by Jessie Y.C. Chen and Peter I. Terrence

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14. ABSTRACT
In this study, we simulated a generic mounted environment and conducted an experiment to examine the performance and workload of the combined position of gunner and robotics operator. More specifically, we compared the performance and workload of the operator when his/her gunnery tasks were assisted by the aided target recognition (ATR) capabilities (delivered through tactile cueing or a combination of tactile and visual cueing) versus when the gunnery task was unassisted. While performing gunnery tasks, participants also had to control a semi-autonomous unmanned ground vehicle (UGV) or tele-operate a UGV. Participants also performed a tertiary communication task concurrently. Results showed that participants' gunnery task performance improved significantly when it was assisted by ATR. The performance of those participants with higher spatial ability exceeded that of participants with lower spatial ability. It was also found that significantly fewer neutral targets (which were not cued) in the gunnery environment were detected (which implies less visual attention being devoted to the gunnery station) when participants concurrently tele-operated a robotic asset or when the gunnery task was assisted by ATR. Participants' robotics (tele-operation) task improved significantly when the ATR was available to assist them with their gunnery task. It was also found that the performance gap between those participants with higher and lower spatial ability appeared to be narrower when the ATR was available. A similar pattern was also observed for the perceived attentional control factor. Participants' communication task performance also improved significantly when the gunnery task was assisted by ATR. Finally, participants' perceived workload was significantly influenced by the type of robotics tasks and whether the gunnery task was assisted by ATR. Participants' perceived workload was significantly higher when they tele-operated a robotic asset and when their gunnery task was unassisted. In a post-experimental survey, 65% of the participants indicated that they relied predominantly on the tactile cues when tactile and visual displays were available; only 15% said they relied primarily on the visual cues. Those who preferred visual cuing tended to have lower spatial ability, and their gunnery and robotics task performance tended to be inferior.

15. SUBJECT TERMS
gunner; multi-tasking; multimodal; robotic operator performance; simulation; tactile display

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The authors wish to thank Jon Bornstein of ARL and his group for providing the system integration laboratory (SIL) for our experiment. We would also like to acknowledge Raymond Compton and Henry Marshall of the U.S. Army Research, Development, and Engineering Command, Simulation and Training Technology Center for all their efforts in acquiring the SIL. We further thank Gary Green and his group of UCF's Institute for Simulation and Training for their support. In particu-lar, Andrew Houchin was an integral part of this research effort, and his excellent work made our data collection and extraction process very smooth.

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1. Introduction

1.1 Purpose

The goal of this research is to examine if gunners in a Future Combat System (FCS) type of mounted environment can effectively maintain local security (i.e., perform their gunnery tasks) while managing their unmanned assets if their gunnery tasks are assisted by aided target recognition (ATR) capabilities. According to Mitchell (2005), which examined workload for Mounted Combat System (MCS) crew members using Improved Performance Research Integration Tool (IMPRINT) modeling, the gunner is the most viable option for controlling robotic assets compared to the other two positions (i.e., vehicle commander and driver). Mitchell found that the gunner had the fewest instances of overload and could assume control of the robotic tasks. However, she also discovered that there were instances in the model when the gunner dropped his primary tasks of detecting and engaging targets to perform robotic control tasks, which could be catastrophic for the team and mission during a real operation.

1.2 Background

Based on Mitchell's modeling work, Chen and Joyner (2006) conducted a simulation experiment that supported the modeling results and showed that when the robotics operator must perform robot targeting and local security (i.e., gunner's tasks) at the same time, both workload and performance degraded. Their results showed that the gunner's target detection performance degraded significantly when participants had to concurrently monitor, manage, or tele-operate an unmanned ground vehicle (UGV) compared with the baseline condition when they only had to perform the gunnery task. As the robotics task became more challenging, participants' gunnery performance degraded accordingly. Their gunnery performance was worst when they had to tele-operate a robot simultaneously. For the robotic tasks, participants' performance was lowest when they controlled a semi-autonomous UGV (only 53% of the targets were detected). Participants' perceived workload was lowest in the single-task condition. As the robotics task became more difficult, the workload increased accordingly, with the tele-operation condition being the highest.

In the current study, we examined if and how tactile cueing, which delivered simulated ATR information to the operator, enhanced the gunner's performance in a multi-tasking environment similar to Chen and Joyner's (2006). Terrence, Brill, and Gilson (2005) compared spatial auditory and spatial tactile cues and found that participants perceived the tactile cues faster and more accurately. In a recent U.S. Army Research Laboratory (ARL) study by Krausman, Elliott, and Pettitt (2005), tactile cueing was not found to be more effective than auditory cueing in terms of response time, although it was more effective than visual cueing. Additionally, participants rated tactile cueing as the most helpful among the three types of alerts. Although tactile stimulation

does appear to have the ability to impact spatial attention at a neurophysiological level (Kennett, Eimer, Spence, & Driver, 2001), spatial attention has been found to have cross-modal links across visual, auditory, and tactile inputs (Spence & Driver, 1997). The level of effectiveness of one spatial information display relative to other display modalities may depend on the operational context of the experimental procedure (i.e., the demands of the tasks). Ho, Tan, and Spence (2005) found that vibrotactile alerts were powerful directors of spatial attention in simulated driving scenarios, with faster responses even when reliability levels made the alerts spatially non-predictive. Segond, Weiss, and Sampaio (2005) found that tactile spatial information could be used to entirely supplant visual information to navigate a robot through a maze, although navigation was the only task performed in this case.

1.3 Current Study

In this study, we replicated the conditions of Chen and Joyner (2006) and incorporated signals (tactile or a combination of tactile and visual) to help participants locate potential threats in the immediate environment while they controlled an unmanned system in a divided attention paradigm. The surrogate gunner primary task was to determine the action to take, based on a visual determination of whether a potential threat was hostile or neutral, while other tasks were being conducted (including the remote targeting task with the robot and a concurrent communication task). It was hypothesized that tactile signals would improve performance in the gunnery and the robotic control tasks since it would alleviate the draw that target scanning has on visual resources. Effects of individual difference factors such as spatial ability and perceived attentional control were also evaluated.

2. Method

2.1 Participants

A total of 20 students (4 females and 16 males) were recruited from the University of Central Florida (UCF) and participated in the study. The ages of the participants ranged from 18 to 38 (*mean [M]* = 20.95, *standard deviation [SD]* = 4.62). Participants were compensated $8 per hour and were given class credit for their participation in the experiment.

2.2 Apparatus

2.2.1 Simulators

2.2.1.1 Tactile Control Unit (TCU)

The experiment was conducted with a TCU developed by the ARL's Robotics Collaborative Technology Alliance (RCTA) for the robotic control tasks. The TCU is a one-person crew station

from which the operator can control several simulated robotic assets that can perform their tasks semi-autonomously or be tele-operated (see figure 1). The operator switched operation modes and display modes through the use of a 19-inch touch-screen display. A joystick was used to manipulate the direction in which the unmanned vehicles moved when in Teleop mode. The UGV simulated in our study is the experimental unmanned vehicle developed by the ARL. The simulation program used in this study was rSAF (robotic semi-automated forces), which is a version of OneSAF for robotics simulation.

Figure 1. User interface of RCTA TCU.

2.2.1.2 Gunnery Station

The gunnery component was implemented with an additional screen and controls to simulate the out-the-window (OTW) view and line-of-sight (LOS) fire capabilities. The interface consisted of a 15-inch flat panel monitor and a joystick (see figure 2). Participants used the joystick to rotate the sensors 360 degrees, zoom in and out, switch between firing modes, and engage targets. In each scenario, there were 10 hostile targets and 10 neutral targets (i.e., civilians) scattered throughout the simulated environment.

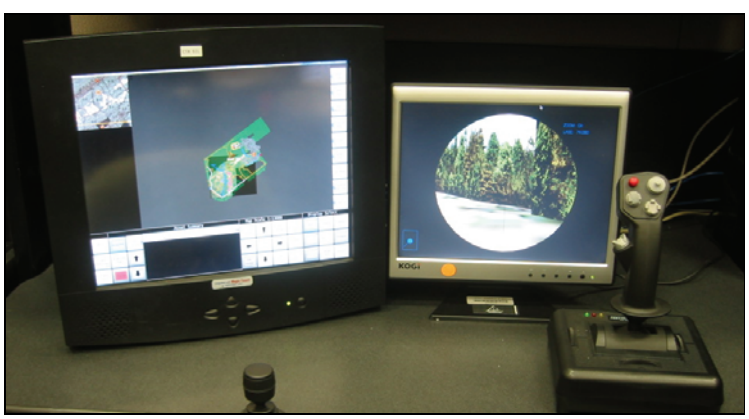

Figure 2. TCU (left) and gunnery station (gunner's OTW view) (right).

2.2.1.3 ATR Systems - Tactile and Visual Alerts

To augment target detection in the gunnery component, visual and tactile alerts were used to cue the participant to the direction of a target, as determined by the ATR. Visually, the targets consisted of icons presented around the overhead view diagram of the participant vehicle in the lower right area of the screen. The target icon appeared in one of eight possible locations around the gunner, corresponding to 45-degree increments along a 360-degree azimuth. As the gunner rotated the view, the turret portion of the vehicle diagram moved along the eight possible orientations to allow the gunner to place his/her field of view (FOV) on the cued target. Tactually, target positions relative to the gunner were presented via eight electromechanical transducers known as "tactors" (see figure 3).

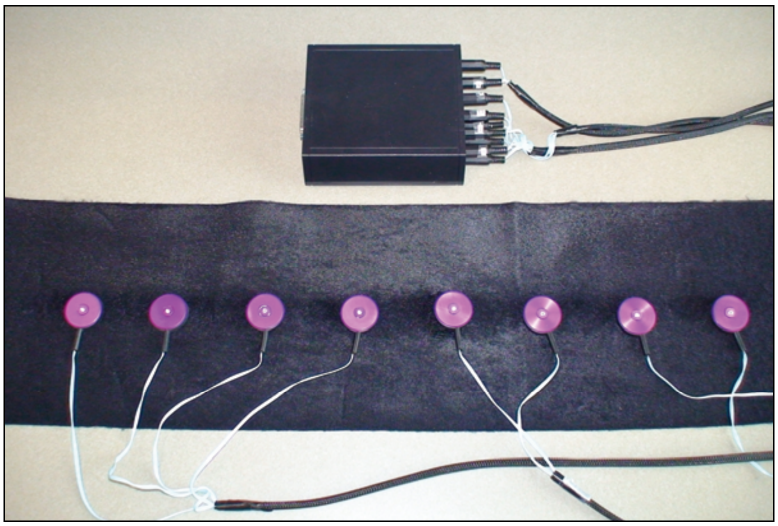

Figure 3. Tactile system.

Each tactor delivered a 250-Hz sinusoidal, salient (approximately 20 dB above threshold) vibrotactile stimulus harmlessly to the skin via the central plunger. The eight tactors were arranged equidistantly on an elasticized belt worn around the abdomen just above navel height. This configuration was based upon research conducted by Cholewiak, Brill, and Schwab (2004) who found that additional tactors within this ring reduced inter-tactor distance and compromised localization performance. This configuration had also proved comfortable to wear for experimental sessions, in the laboratory and in the taxing field conditions. The tactile stimulus parameters were programmed onto a battery-powered controller board governing all eight tactors. This board was, in turn, controlled by a computer running the simulation and presenting targets for the visual and tactile conditions. The tactile stimulus had a 300-ms duration, which was determined based upon the simulation's refresh rates for revising ATR information. To match the visual condition as closely as possible, a target that was directly behind the gunner (6 o'clock position) caused the tactor on the spine to activate. If the gunner moved the turret to the right, the vibrotactile stimulus appeared to move along the right side of the body to the front-most tactor where the target was

now in the gunner's FOV. Participants had an opportunity to become familiar with both types of signals during the training session.

2.2.2 Communication Task

The communication task was administered concurrently with the experimental scenarios. The questions included simple military-related reasoning tests and simple memory tests. The inclusion of these cognitive tasks was for simulating an environment where the gunner was communicating with fellow crew members in the vehicle. For the reasoning tests, there were questions such as "if the enemy is to our left, and our UGV is to our right, what direction is the enemy to the UGV?" For the memory tests, the participants were asked to repeat some short statements or keep track of three radio call signs (e.g., Bravo 83) and they had to report to the experimenter whether the call signs they heard were one of those they were keeping track. Test questions were delivered by a synthetic speech program, DECTalk[1]. The questions were pre-recorded by a male speaker and presented at the rate of one question every 33 seconds.

2.2.3 Questionnaires and Spatial Tests

A demographics questionnaire was administered at the beginning of the training session (appendix A). A questionnaire on Attentional Control (appendix B) (Derryberry & Reed, 2002) was used to evaluate participants' perceived attentional control (PAC). The Attentional Control survey consists of 21 items and measures attention focus and shifting. The Cube Comparison (Cube for short) and the Hidden Figures/Patterns tests (Hidden Figures for short) (Educational Testing Service, 2007a&b) as well as the Spatial Orientation Test (Orientation for short) were used to assess participants' spatial ability (SpA). The Cube test requires participants to compare, in 3 minutes, 21 pairs of six-sided cubes and determine if the rotated cubes are the same or different. The Hidden Figures test measures flexibility of closure and involves identifying specific patterns or shapes embedded within distracting information. The Orientation test, constructed by Dr. Paula Durlach of the U.S. Army Research Institute, is modeled after the cardinal direction test developed by Gugerty and his colleagues (Gugerty & Brooks, 2004) and is a computerized test consisting of a brief training segment and 32 test questions. Accuracy and response time were automatically captured by the program.

Participants' perceived workload was evaluated with the computer-based version of National Aeronautics and Space Administration-task load index (NASA-TLX) questionnaire (appendix C) (Hart & Staveland, 1988). The NASA-TLX is a self-reported questionnaire of perceived demands in six areas: mental, physical, temporal, effort (mental and physical), frustration, and performance. Participants were asked to evaluate their perceived workload level in these areas on 10-point scales. They also assessed the contribution (i.e., weight) of each factor to the perceived workload by comparing the 15 possible pairs of the six factors. According to Noyes and Bruneau (2007),

[1]DECtalk is a registered trademark of Digital Equipment Corporation.

computer-based NASA-TLX tends to generate higher workload ratings compared with the traditional paper-based survey. However, since the ratings were used to compare the workload levels across the experimental conditions, the elevated ratings should not affect these comparisons.

The Simulator Sickness Questionnaire (SSQ, see appendix D) was used to evaluate participants' simulator sickness symptoms (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The SSQ consists of a checklist of 16 symptoms, each of which is related in terms of degrees of severity (none, slight, moderate, severe). A total severity (TS) score was derived by a weighted scoring procedure and reflected overall discomfort level.

Finally, a usability questionnaire on the tactile/visual ATR displays was constructed (see appendix E). Participants indicated their level of reliance on tactile and/or visual cueing for the gunnery task when both types of alerts were available. They also indicated their perceived usability of the ATR displays.

2.3 Experimental Design

The overall design of the study is a 2 x 3 repeated measures design. The independent variables are ATR type (Baseline-no alerts versus Tactile alerts only versus Tactile + Visual alerts) and Robotics Task type (Auto versus Teleop). There were six conditions:

- *Auto-BL* (baseline): No alerts + control of a semi-autonomous UGV
- *Teleop-BL*: No alerts + Tele-operating a UGV
- *Auto-Tac*: Tactile alerts + control of a semi-autonomous UGV
- *Teleop-Tac*: Tactile alerts + Tele-operating a UGV
- *Auto-TacVis*: Tactile alerts + Visual alerts + control of a semi-autonomous UGV
- *Teleop-TacVis*: Tactile alerts + Visual alerts + Tele-operating a UGV

The reliability level of the alerts was 100%. However, only hostile targets were cued, not the neutral targets. The participants had to detect the neutral targets on their own.

2.4 Procedure

After being briefed about the purpose of the study, the tasks for the experiment, and any risks involved, participants read and signed a consent form. Then they answered the Attentional Control survey and were administered the spatial ability tests (i.e., Cube, Hidden Figures, and Orientation). After these tests, participants received training, which lasted approximately 2 hours. Training was self-paced and was delivered by PowerPoint[2] slides showing the elements of the TCU, steps for completing various tasks, several mini-exercises for practicing the steps, and two exercises for performing the robotic control tasks (one for practicing the tele-operation task and one for

[2]PowerPoint is a registered trademark of Microsoft Corporation.

practicing the UGV control tasks). After the tutorial on TCU, participants were trained in the gunnery tasks. The entire training session lasted about 2.5 hours.

The experimental session took place on a different day but within a week of the training session. Before the experimental session began, participants were given some practice trials and review materials, if necessary, to refresh their memories. After the refresher training, participants completed one combined exercise in which they performed all three tasks (i.e., gunnery, robotic control, and communication tasks) at the same time. At this point, all tutorial materials and information were removed and the participants had to be able to perform all these tasks on their own. After this final exercise, the experimenter determined if the participant needed any further practice on the robotic control tasks or gunnery tasks and provided some further training and exercises if necessary. Participants had to demonstrate that they could recall all the steps for performing the tasks without any help.

Before the experimental session began, participants changed into one of the laboratory cotton T-shirts in order to standardize how the tactors were applied to the skin. They chose a size and then were escorted to the restroom where they could change privately. Then the experimenter asked to measure the participant around the abdomen just above navel height so that the tactile display could be custom fitted. After taking this measurement, the experimenter arranged the tactors so that they were equidistant for the participant's abdomen. Once fitted with the tactile display, the participant was seated in front of the gunner monitor. A test pattern confirmed that all eight tactors were working properly and that the participant could readily perceive the stimuli. The experimenter then explained the nature of the ATR system and the corresponding visual or tactile cues that would be provided.

In the experimental trials, participants' tasks were to use their robotic asset to locate targets (i.e., enemy dismounted Soldiers) in the remote environment and to find targets in their immediate (i.e., MCS) environment. The MCS was simulated as traveling along a designated route, which was approximately 4.3 km and lasted about 15 minutes. There were 10 hostile and 10 neutral targets (i.e., civilians) along the route in each gunnery scenario. Participants were instructed to engage the hostile targets and verbally report spotting the neutral targets. In total, there were six 15-minute scenarios, corresponding to the six experimental conditions, the order of which was counterbalanced across participants.

There were two types of robotics tasks: Auto and Teleop. The Auto control task required the operator to monitor the video feed as the UGV traveled autonomously, to examine still images generated from the RSTA (reconnaissance, surveillance, and target acquisition) scans, and detect targets. The Teleop task required the operator to manually manipulate and drive the UGV (using a joystick) along a predetermined route using the TCU to detect targets. For both the Auto and Teleop tasks, upon detecting a target, participants needed to place the target on the map, label the target, and then send a spot report. A list of robotic tasks for the Auto and Teleop conditions is presented in table 1.

Table 1. Robotic tasks for the Auto and Teleop conditions.

Condition	Auto	Teleop
Tasks	Identify target or neutral by analyzing RSTA scans	Identify target or neutral
	Verbally report neutrals	Verbally report neutrals
	Queue target (i.e., add to map)	Switch to Map Display
	Switch to Map Display	Add target to the map manually
	Label target	Label target
	Submit Spot Report	Submit Spot Report

While the participants were performing their gunnery and robotics control tasks, they simultaneously performed the communication task by answering questions delivered to them via DECtalk.

There were 2-minute breaks between experimental scenarios. Participants assessed their workload using the NASA-TLX after they completed each scenario. At the conclusion of all scenarios, participants were administered the SSQ, used to evaluate the severity of their simulator sickness symptoms. The participants also completed a usability questionnaire regarding the tactile/visual cueing systems at the end of the experimental session. The entire experimental session lasted about 3 hours.

2.5 Measures

The dependent measures include mission performance (i.e., number of targets detected in the remote environment by the robotic asset and number of hostile/neutral targets detected in the immediate environment), communication task performance, and perceived workload. Since participants' robotics task performance in the Auto condition was limited by the capabilities of the TCU (i.e., accuracy of the RSTA scans), it was determined that only the performance data from the Teleop condition would be analyzed.

3. Results

3.1 Target Detection Performance

3.1.1 Gunnery Tasks

Table 2 lists several measures relating to target detection. Participants were designated as high SpA or low SpA, based on their composite spatial ability test scores (median split). A mixed analysis of variance (ANOVA) was performed to examine the effects of the concurrent robotic control tasks on the gunnery task performance (percentage of hostile targets detected), with the Robotics Task condition (Auto versus Teleop) and the ATR condition (Baseline versus Tac versus TacVis) being the within-subject factors and SpA (High versus Low) as the between-subject

factor. The ANOVA revealed that ATR condition significantly affected the number of targets detected, $F(2, 36) = 78.623$, $p < .001$. *Post hoc* tests (Least Significant Difference or LSD) showed that target detection in the Baseline condition was significantly lower than in the Tac and TacVis conditions. Participants with higher SpA had significantly higher gunnery task performance than did those with lower SpA, $F(1, 18) = 5.659$, $p < .05$ (figure 4).

Table 2. Mean proportion of targets detected (standard deviations are presented in parentheses).

Measures	**Auto**			**Teleop**		
	Baseline	**Tac**	**TacVis**	**Baseline**	**Tac**	**TacVis**
Gunnery Task (Hostile only)	.550[a] (.193)	.840[b] (.143)	.844[b] (.114)	.495[a] (.196)	.832[b] (.162)	.859[b] (.092)
Gunnery Task (Neutral only)	.485[a] (.187)	.280[b] (.128)	.354[b] (.148)	.425[c] (.241)	.189[d] (.091)	.260[d] (.126)
Robotic Task (Teleop only)	NA	NA	NA	.690[a] (.290)	.780[a] (.190)	.786[a] (.227)
Communication Task	.862[a] (.104)	.890[b] (.073)	.899[b] (.110)	.847[a] (.108)	.873[b] (.083)	.882[b] (.123)

Note: Statistics with the same superscript are not significantly different from one another

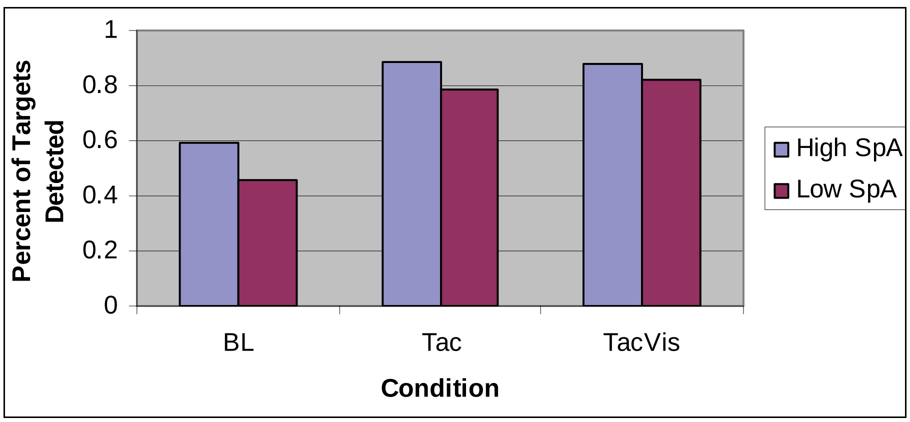

Figure 4. Effects of spatial ability on gunner's hostile target detection performance.

Participants' detection of neutral targets was also assessed. Since the ATR only alerted the participants when hostile targets were present, the neutral target detection could be used to indicate how much visual attention were devoted to the gunnery station. Performance data from the Tac and TacVis conditions were merged to form the ATR condition and were compared with the Baseline condition. An ANOVA revealed a significant main effect for both Robotics, $F(1,16) = 10.407$, $p < .01$, and ATR, $F(2,32) = 15.272$, $p < .001$ (figure 5). *Post hoc* tests (LSD) showed that neutral target detection in Baseline was significantly higher than in the Tac and TacVis conditions; TacVis was also significantly higher than Tac.

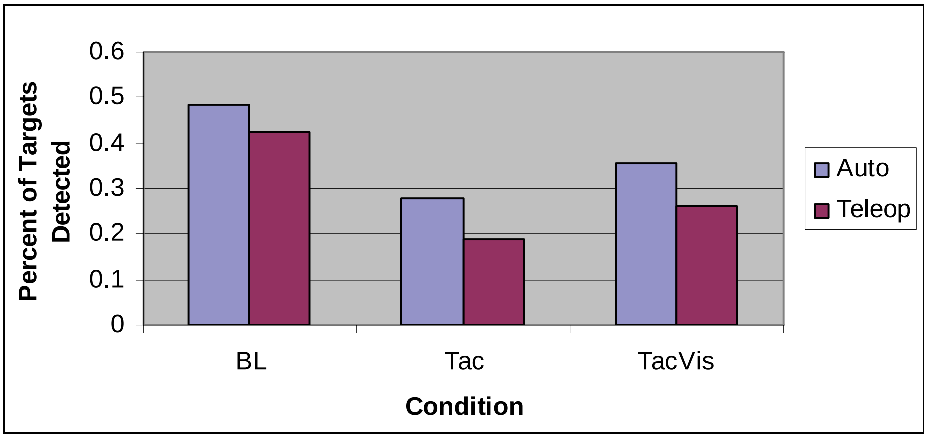

Figure 5. Gunner's neutral target detection performance.

3.1.2 Robotics Tasks

Since the participants' task performance in the Auto condition was limited by the capabilities of the TCU, it was determined that only the performance data from the Teleop condition would be included for the analyses. Performance data from the Tac and TacVis conditions were again merged to form the ATR condition and were compared with the Baseline condition. The Baseline condition was found to be significantly lower than the ATR condition, $F(1,18) = 5.342$, $p < .05$. The performance of participants with higher SpA exceeded that of those with lower SpA in the baseline condition, $F(1,18) = 5.851$, $p < .05$, but not in the ATR conditions (figure 6). Similarly, the performance of participants with high PAC exceeded that of those with lower PAC in the baseline condition (although the difference was only marginally significant, $F(1,18) = 4.343$, $p = .052$) but not in the ATR conditions.

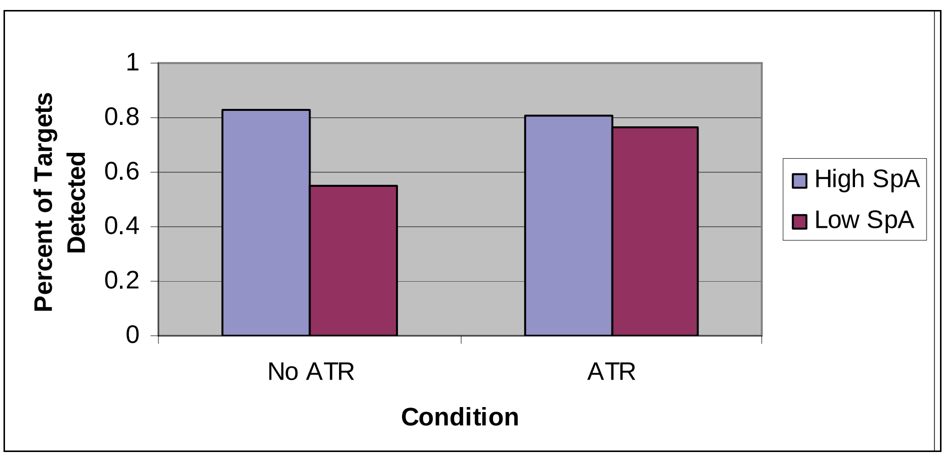

Figure 6. Effects of spatial ability on robotics task performance.

3.2 Communication Task Performance

Performance data from the Tac and TacVis conditions were again merged to form the ATR condition and were compared with the Baseline condition. The difference between these two conditions was significant, $F(1, 19) = 7.416$, $p < .05$, with the no ATR condition lower (figure 7). No significant correlations between communication performance and the individual difference factors (i.e., SpA and PAC) were observed.

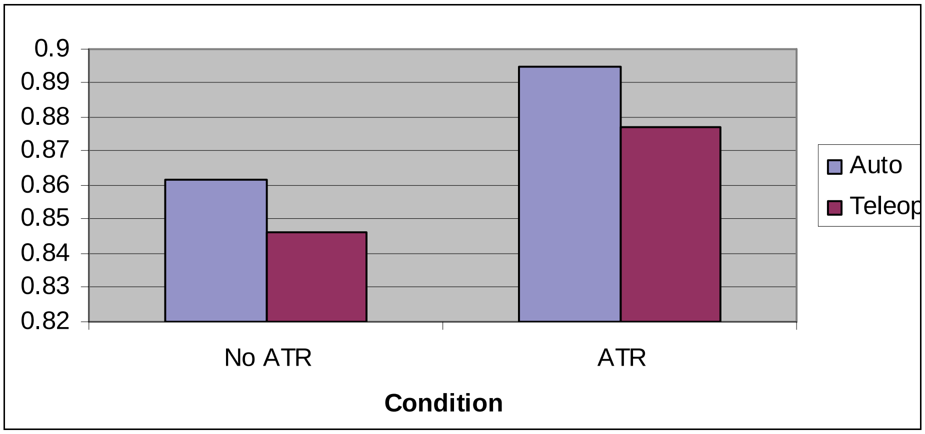

Figure 7. Communication task performance.

3.3 Perceived Workload

Weighted ratings of the scales of the NASA-TLX were used for this analysis. Participants' self-assessment of workload was significantly affected by the Robotic condition, $F(1, 18) = 5.212$, $p < .05$, as well as the ATR condition, $F(2,32) = 4.30$, $p < .05$ (figure 8). The perceived workload was higher in the Teleop condition ($M = 70.22$) and when the gunnery task was unassisted by the ATR ($M = 70.54$). No significant correlations between perceived workload and the individual difference factors (i.e., SpA and PAC) were observed.

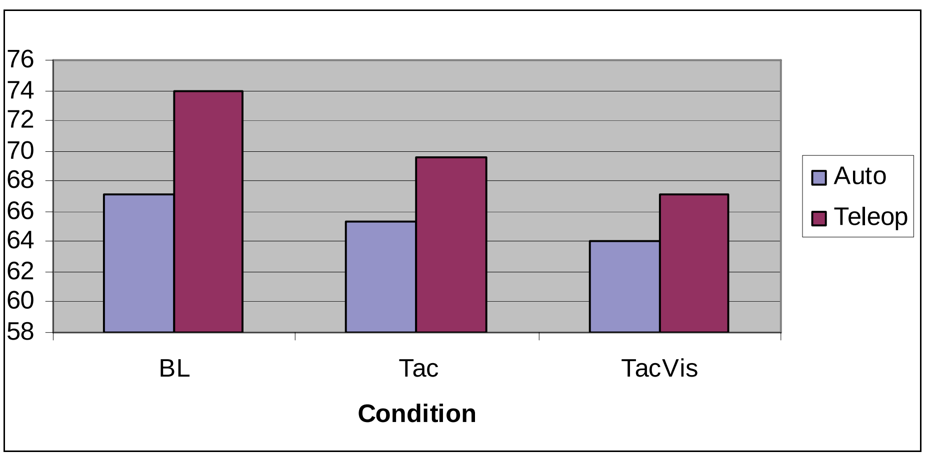

Figure 8. Perceived workload.

3.4 Simulator Sickness

Participants' simulator sickness scores (SSQ: three sub-scales and the total severity score [TSS]) were calculated, based on the formulae in Kennedy et al. (1993) (see appendix F for the scoring procedure). The average TSS was 32.69 (*SD* = 32.87), which was not significantly different from the TSS reported in Chen and Joyner (2006). Additional, no significant correlations were found between TSS and attentional control, amount of sleep, or the spatial tests. There was a significant correlation between simulator sickness and workload ratings for tactile-visual ATR (two-tailed Pearson $r = .500$, $p = .030$, N = 19; ratings summated across robotics conditions). A mixed ANOVA with simulator sickness as coded into high and low levels (using a median split) yielded no significant findings for gunner performance across ATR type, enemy/neutral detection, and robotics task type.

3.5 Usability Questionnaire

A usability questionnaire captured participant preferences for presentation of ATR information. Following their interaction with the ATR systems, 65% of participants responded that they relied predominantly or entirely on the tactile ATR display. Only 15% responded that they relied predominantly or entirely on the visual ATR display. ATR preference was also significantly correlated with attentional control scores (two-tailed Pearson $r = .482$, $p = .031$, N = 20) as well as the composite score of the spatial tests (two-tailed Pearson r = .532, $p = .016$, N = 20).

A mixed ANOVA on gunner performance for detecting enemy targets was conducted with Robotics task type as a within-subject factor and ATR preference as a between-subject factor. There was a main effect for ATR preference, $F(2,17) = 3.995$, $p < .05$ (figure 9). *Post hoc* tests revealed that those who indicated a strong preference for visual ATR performed significantly worse than those who preferred to have both or tactile alone. The performance for those who preferred tactile did not differ significantly from those who indicated that they relied on both. Caution must be taken with these results since the cell sizes for indicated preferences are not equal.

A similar ANOVA on gunner performance for detecting neutral targets did not yield any significant findings with respect to ATR preference. However, another mixed ANOVA examining robotics task performance with ATR as a within-subject factor and ATR preference as a between-subject factor did yield a significant main effect for ATR preference, $F(2,17) = 4.177$, $p < .05$. *Post hoc* analyses showed higher performance for tactile ATR preference over those who preferred visual ATR. No significant differences were found between those who preferred both and tactile and vision.

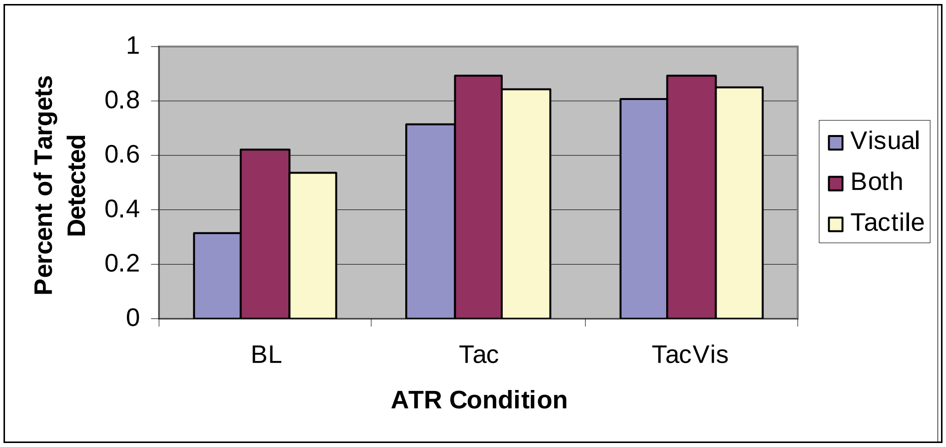

Figure 9. ATR preference and gunnery performance.

4. Discussion

In this study, we simulated a generic mounted environment and conducted an experiment to examine the performance and workload of the combined position of gunner and robotic operator. More specifically, we compared the performance and workload of the operator when his or her gunnery tasks were assisted by ATR capabilities (delivered through tactile cueing or a combination of tactile and visual cueing) versus when the gunnery task was unassisted. Results showed that the gunner's target detection performance improved significantly when his/her task was assisted by ATR. Consistent with the findings of Chen and Joyner (2006), participants' SpA was found to be an accurate predictor of their gunnery performance. The performance of participants with higher SpA consistently exceeded that of those with lower SpA throughout the scenarios.

It was also found that gunner's detection of neutral targets (which was not aided by ATR) was significantly worse when s/he had to tele-operate a robotic asset (versus when the asset was semi-autonomous) or when the gunnery task was aided by ATR. This finding suggests that participants devoted significantly less visual attention to the gunnery station when their robotic asset required tele-operation or when their gunnery task was assisted by ATR. On average, participants detected 45% of the neutral targets when there was no ATR; they only detected 28% when there was. Results of the current study are consistent with automation research that operators may develop over-reliance on the automatic system and this complacency may negatively affect their task performance (Chen & Joyner, 2006; Parasuraman, Molloy, & Singh, 1993; Thomas & Wickens, 2000; Young & Stanton, 2007). It is worth noting that these findings, along with the results of the current study, do not necessarily suggest that manual manipulation of sensor devices be used instead of ATR devices. However, the issue of over-reliance on these automatic capabilities needs to be taken into account when one is designing the user interface where these features are part of the components.

For the robotics tasks, since the participants' task performance in the Auto condition was limited by the capabilities of the TCU and therefore could not indicate their true performance, only the performance data from the Teleop condition were used for the analyses. The results showed that participants' tele-operation performance improved significantly when their gunnery task was assisted by ATR. Therefore, ATR was not only beneficial for the automated task (i.e., gunnery) but also the concurrent task (i.e., robotics). Additionally, it was evident that ATR was more beneficial for enhancing the concurrent robotics performance for those with lower SpA than for those with higher SpA. Similarly, ATR appeared to benefit those with lower PAC more than those with higher PAC. When ATR was available to assist those operators with low SpA and PAC, the performance of their concurrent task was improved to a similar level as those with higher SpA and PAC. These results may have important implications for system design and personnel selection for the Army's FCS program.

The participants' communication task performance improved when their gunnery task was aided by ATR. Again, this result suggests that ATR not only enhanced the tasks it was designed for, but it also benefited concurrent tasks. It also shows that our cognitive communication task was sensitive to the task load manipulations we implemented for the primary task (ATR versus no ATR). However, unlike Chen and Joyner (2006), those with higher PAC were not found to outperform those with lower PAC. Further research is needed to examine the relationship between attentional resource management and concurrent task performance.

The participants' perceived workload was found to be affected by the type of concurrent robotic task as well as whether their gunnery task was aided by ATR. They had a higher workload level when their gunnery task was unassisted by ATR. They also experienced significantly higher workload when they tele-operated the robotic asset. These results are consistent with Chen and Joyner (2006) and Schipani (2003), which evaluated robotic operator workload in a field setting. Although many of the ground robotic assets in the Army's FCS program will be semi-autonomous, tele-operation will still be an important part of any missions involving robotic assets (e.g., when robots encountered obstacles or other problems). The higher workload associated with tele-operation needs to be taken into account when one is designing the user interfaces for the robotic assets.

Reported simulator sickness did not serve as a meaningful covariate with performance on both the gunner task and tele-operating the UGV. Overall, participants' simulator sickness seemed slightly more severe than in Chen and Joyner (2006), although the difference was not statistically significant. We did not find differences between those with higher and lower attentional control, as reported in Chen and Joyner (2006).

The significant positive correlation of ATR preference with the composite score of spatial tests is interesting, since it appeared that as ATR ratings tended toward considerable reliance on the tactile display, there was a concurrent shift with higher performance on the spatial tests. Perhaps those with higher spatial ability can more easily employ the spatial tactile signals in the dual task setting

and therefore have a stronger preference for something that makes the gunner's task easier to complete. Individuals with lower spatial ability, on the other hand, may have not used the spatial tactile cues to their full extent and therefore continued to prefer the visual ATR display. According to Kozhevnikov, Hegarty, and Mayer (2002), visualizers with lower spatial ability tend to rely on iconic imagery while those with higher spatial ability tend to prefer using spatial-schematic imagery while solving problems. Therefore, it is likely that, in our study, those who preferred visual ATR displays may have been more iconic in their mental representations. However, this preference may have caused degraded target detection performance because of more visual attention being devoted to the visual ATR display instead of the simulated environment. In contrast, those who were more spatial relied on the directional information of the tactile display to help them with the visually demanding tasks, which resulted in a more effective performance. Additional research using multimodal spatial information in this experiment test bed could help to determine the appropriate methods for displaying new technological information advancements and better aid mounted Soldiers in field settings.

The ATR preference was also significantly correlated with Attentional Control Scores, thus indicating a relationship between preference for the tactile ATR display and higher attentional control. Since the dual visual task of operating the TCU and the gunner station places a large burden on the visual resources, the tactile ATR display may allow limited attention resources to be time shared in a more effective manner by transferring a large amount of the search task in the gunnery station from the visual to the tactile domain with the use of the ATR, particularly for those with higher reported attentional control. However, a cautionary note is offered since the ratings data may not be truly interval in nature and therefore, the correlations may not provide entirely reliable information. Additional research should be directed at using multimodal displays to overcome spatial ability and attentional limitations in these demanding multi-task environments.

5 Conclusions

In this study, we conducted a simulation experiment and examined the effectiveness of ATR capabilities (delivered through tactile cueing or a combination of tactile and visual cueing) for enhancing the performance of gunners who also had to simultaneously operate a UGV and maintain effective communication with fellow crew members. We did not include a visual-cueing-only condition and decided to focus on the tactile display so we could determine the value of providing non-visually dependent aid to the operators to help them with their tasks in the visually intensive environment we created. Since both types of cues were provided in the TacVis condition, participants could choose to use either type or both. Therefore, we could still examine the effect of using visual cueing predominantly, although admittedly, not in a statistically meaningful way, since only 15% of our participants relied primarily on visual cueing.

Overall, our findings suggest that, in a multi-tasking environment such as the one simulated in this study, automation (i.e., ATR in this study) for one task benefits not only the automated task but also the concurrent tasks (i.e., robotics and communication in this case). However, operators may develop over-reliance on the ATR for their tasks and may overlook other developments that are not detected by the system (e.g., the neutral targets in the current study). Since the reliability level of the ATR was set at 100% in this study, it would be interesting to see how ATR with imperfect reliability would affect an operator's visual attention. In an ensuing study, both false-alarm-prone and miss-prone ATR will be simulated and their effects will be examined. Additionally, we select personnel for simultaneously performing gunnery and robotic tasks, it might be beneficial to take into account their spatial ability. Chen et al. (in press) and Chen and Joyner (2006) and the current study all demonstrated the superior performance by those with higher spatial ability. It is especially important if ATR is not available to assist the operators with their tasks. These data on individual differences can be used in future IMPRINT modeling efforts as input data to modeling tasks and therefore enhance future model analyses. Finally, both visual and tactile cueing should be provided in future military mounted environments such as the one simulated in the current study. It seems that low-SpA individuals prefer visual cueing over tactile cueing, although tactile display would be more effective in a highly visual environment (so visual attention can be devoted to the tasks, not on the cues). It is likely that training interventions can be devised to help these low-SpA individuals better employ tactile information.

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Appendix A. Demographic Questionnaire

Participant # _______ Age ______ Major ________________ Date ___________ Gender ___

1. What is the highest level of education you have had?
Less than 4 yrs of college ____ Completed 4 yrs of college ____ Other ____

2. When did you use computers in your education? (*Circle all that apply*)

Grade School	Jr. High	High School
Technical School	College	Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other________ Do Not Use

4. For each of the following questions, circle the response that best describes you.

How often do you:	
Use a mouse?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a joystick?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a touch screen?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use icon-based programs/software?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use programs/software with pull-down menus?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use graphics/drawing features in software packages?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use E-mail?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Operate a radio controlled vehicle (car, boat, or plane)?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play computer/video games?	Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer? (check √ one)
_____ Novice
_____ Good with one type of software package (such as word processing or slides)
_____ Good with several software packages
_____ Can program in one language and use several software packages
_____ Can program in several languages and use several software packages

7. Are you in your usual state of health physically? YES NO
If NO, please briefly explain:

8. How many hours of sleep did you get last night? ______ hours

9. Do you have normal color vision? YES NO

10. Do you have prior military service? YES NO If Yes, how long __________

INTENTIONALLY LEFT BLANK

Appendix B. Attentional Control Survey

For each of the following questions, circle the response that best describes you.

It is very hard for me to concentrate on a difficult task when there are noises around.
Almost never, Sometimes, Often, Always

When I need to concentrate and solve a problem, I have trouble focusing my attention.
Almost never, Sometimes, Often, Always

When I am working hard on something, I still get distracted by events around me.
Almost never, Sometimes, Often, Always

My concentration is good even if there is music in the room around me.
Almost never, Sometimes, Often, Always

When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.
Almost never, Sometimes, Often, Always

When I am reading or studying, I am easily distracted if there are people talking in the same room.
Almost never, Sometimes, Often, Always

When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.
Almost never, Sometimes, Often, Always

I have a hard time concentrating when I'm excited about something.
Almost never, Sometimes, Often, Always

When concentrating, I ignore feelings of hunger or thirst. Almost never, Sometimes, Often, Always

I can quickly switch from one task to another. Almost never, Sometimes, Often, Always

It takes me a while to get really involved in a new task. Almost never, Sometimes, Often, Always

It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures. Almost never, Sometimes, Often, Always

I can become interested in a new topic very quickly when I need to.
Almost never, Sometimes, Often, Always

It is easy for me to read or write while I'm also talking on the phone.
Almost never, Sometimes, Often, Always

I have trouble carrying on two conversations at once. Almost never, Sometimes, Often, Always

I have a hard time coming up with new ideas quickly. Almost never, Sometimes, Often, Always

After being interrupted or distracted, I can easily shift my attention back to what I was doing before.
Almost never, Sometimes, Often, Always

When a distracting thought comes to mind, it is easy for me to shift my attention away from it.
Almost never, Sometimes, Often, Always

It is easy for me to alternate between two different tasks. Almost never, Sometimes, Often, Always

It is hard for me to break from one way of thinking about something and look at it from another point of view.
Almost never, Sometimes, Often, Always

Appendix C. NASA-TLX Questionnaire

Please rate your overall impression of demands imposed on you during the exercise.

1. Mental Demand: How much mental and perceptual activity was required (e.g., thinking, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

2. Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

3. Temporal Demand: How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

4. Level of Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

5. Level of Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

6. Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

LOW |---|---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

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Appendix D. Simulator Sickness (Current Health Status) Questionnaire

ID__________________ Time & Date ___________

Instructions: Please indicate how you feel **right now** in the following areas, by **circling** the word that applies.

1.	General Discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eye Strain	None	Slight	Moderate	Severe
5.	Difficulty Focusing	None	Slight	Moderate	Severe
6.	Increased Salivation	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty Concentrating	None	Slight	Moderate	Severe
10.	Fullness of Head	None	Slight	Moderate	Severe
11.	Blurred vision	None	Slight	Moderate	Severe
12.	Dizzy (Eyes Open)	None	Slight	Moderate	Severe
13.	Dizzy (Eyes Closed)	None	Slight	Moderate	Severe
14.	Vertigo*	None	Slight	Moderate	Severe
15.	Stomach Awareness**	None	Slight	Moderate	Severe
16.	Burping	None	Slight	Moderate	Severe

*Vertigo is a disordered state in which the person or his/her surroundings seem to whirl dizzily: giddiness
** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Are there any other symptoms you are experiencing right now? If so, please describe the symptom(s) and rate its/their severity below. Use the other side if necessary.

INTENTIONALLY LEFT BLANK

Appendix E. Usability Questionnaire

1. **The gunner station should only have the visual ATR display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A Comments
1 2 3 4 5 6 7

2. **I made use of both the visual and tactile ATR displays.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

3. **I sometimes felt 'lost' using the tactile ATR display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

4. **I sometimes felt 'lost' using the visual+tactile display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

5. **The tactile ATR display was intuitive and made it easy to determine the direction of targets.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

6. **The visual+tactile ATR display was helpful when I had to teleoperate the UGV.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

7. **The visual+tactile ATR display was helpful when the UGV was semi-autonomous.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

8. **The gunner station should not have an ATR display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

9. **The tactile ATR display was confusing.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

10. **The visual+tactile ATR display was intuitive and made it easy to determine the direction of targets.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

11. The visual+tactile ATR display was confusing.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

12. The tactile ATR display was annoying.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

13. The visual+tactile ATR display was annoying.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

14. The tactile ATR display improved my performance on the gunner task.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

15. The visual+tactile ATR display improved my performance on the gunner task.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE N/A
1 2 3 4 5 6 7

Which of the following best describes your source of ATR information when you had access to both the visual and the tactile displays (please circle ONE answer only):

1. entirely visual
2. predominately visual
3. both visual and tactile
4. predominately tactile
5. entirely tactile

Appendix F. Scoring Procedure for the Simulator Sickness Questionnaire

Symptoms scored 0 (None) - 3 (Severe)

Nausea (Raw) - Sum of General discomfort, increased salivation, sweating, nausea, diff concentrating, stomach awareness, burping

Nausea sub scale = Nausea (Raw) x 9.54

Oculomotor - Sum of general discomfort, fatigue, headache, eye strain, diff focusing, diff concentrating, blurred vision

Oculomotor sub scale = Nausea (Raw) x 7.58

Disorientation - Sum of diff focusing, nausea, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), vertigo

Disorientation sub scale = Nausea (Raw) x 13.92

TSS = [Nausea (Raw) + Oculomotor (Raw) + Disorientation (Raw)] x 3.74

Glossary of Acronyms

ANOVA	analysis of variance
ARL	Army Research Laboratory
ATR	aided target recognition
FCS	Future Combat System
FOV	field of view
IMPRINT	Improved Performance Research Integration Tool
LOS	line of sight
LSD	Least Significant Difference
MCS	mounted combat system
NASA-TLX	National Aeronautics and Space Administration-task load index
OTW	out the window
PAC	perceived attentional control
RCTA	Robotics Collaborative Technology Alliance
RSTA	reconnaissance, surveillance, and target acquisition
SIL	system integration laboratory
SpA	spatial ability
SSQ	Simulator Sickness Questionnaire
TCU	tactical control unit
TS	total severity
TSS	Total Severity Score
UCF	University of Central Florida
UGV	unmanned ground vehicle

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